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TITLE: CdSe Fractional-Monolayer Active Region of MBE Grown Green [Zn,Mg,Cd] [S,Se] Lasers

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CdSe fractional-monolayer active region of MBE grown green (Zn,Mg,Cd)(S,Se) lasers

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Due to the recent progress in obtaining relatively long-lived GaN-based lasers, the accent of (Mg,Zn,Cd)(S,Se) system laser applications has been shifted to a green region of visible spectrum, which is of great importance for a large-screen projection television and for the applications needed in low-power well-visible by human eye laser pointer. In this paper, a new type of active region using a fractional monolayer (FML) insertion is proposed and studied. As it has been shown previously [1], the wavelength of light emission from single CdSe fractional monolayer (ML) varies from 450 to 530 nm, depending on the nominal CdSe thickness (0.2–3 ML, respectively). Here we focus on the relatively thick insertions (2.5–3 ML) to obtain laser emission in green. At the moment there are contradictory data on the CdSe layer morphology and critical thickness depending on growth conditions. The critical thickness is estimated to be about 3 ML (RHEED oscillations). Particularly, the formation of optically active quantum dots at exceeding this value has been reported [2]. However, there is no reliable data on the intrinsic structure of thin CdSe layer close to the critical thickness as well as on possibility of its application as a laser active region.

All the structures used in this study were grown by molecular beam epitaxy (MBE) on GaAs (001) substrates with a GaAs buffer layer grown in separate III–V MBE setup. The details of MBE growth as well as composition control of quaternary and ternary (ZnMg)SSe and ZnCdSe alloys have been described elsewhere [3, 4]. Both optical and structural (XRD and TEM) characterization techniques were used.

To elucidate the structural and optical quality of FML the structure containing single 2.5 ML CdSe insertion in ZnSe matrix has been grown by migration enhanced epitaxy mode of the MBE technique [1, 5]. Plan-view TEM image of this structure is shown in Fig. 1. One can see a high density of dot-like objects with the average lateral size of 30–40 nm. They seem to be related to CdSe insertion, because such objects are not observed in the plan-view TEM image of the cap ZnSe layer. The TEM image reveals specific defects associated with the largest dot-like objects probably indicating their strain relaxation.

The data on optical characterization of such structure are rather complicated. At low excitation level (tungsten lamp) the spectra of low temperature (5 K) photoluminescence (PL) demonstrate a 40 meV wide single peak near 500 nm. According to the PL excitation spectra the line is non-homogeneous that is also confirmed by the PL time-resolved experiments. The PL spectra at higher excitation level (351 nm line of 20 mW argon laser) show additional feature: weak wide line ($\sim$ 250 meV) at $\sim$ 2.2 eV. This line is commonly attributed in literature to the defects related luminescence. However, the spectra of resonant light scattering also reveal a distinctive line at this energy.

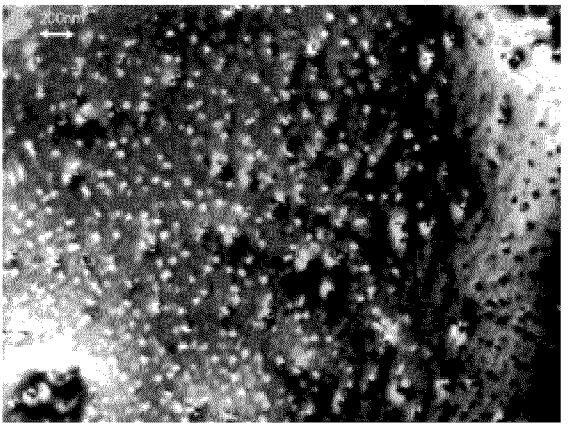

Fig 1. Plan-view TEM image of structure with single CdSe FML.

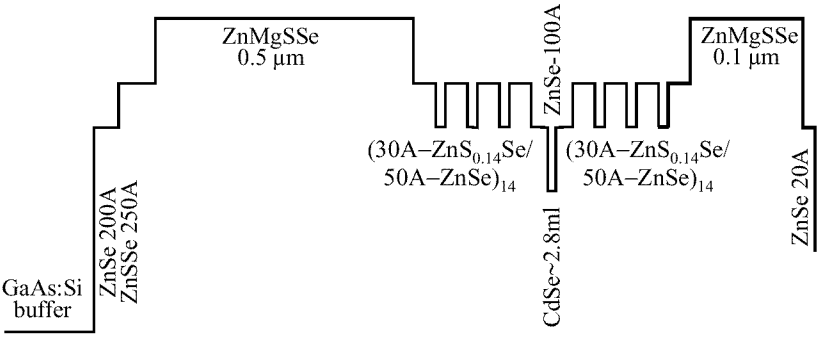

Fig 2. Schematic diagram of structure (**A**).

To check the feasibility of CdSe/ZnSe FML structures (near CdSe critical thickness) as an active region of laser structures the special optically pumped structure have been grown (named below as (**A**)) consisting consequently of 0.5 μm-$Zn_{0.92}Mg_{0.08}S_{0.14}Se_{0.86}$ layer, 0.1 μm-$ZnS_{0.12}Se_{0.88}$/ZnSe SPSL, 10 nm ZnSe quantum well centered with 2.8 ML CdSe insertion, 0.1 μm-$ZnS_{0.12}Se_{0.88}$/ZnSe SPSL and top 0.1 μm-ZnMgSSe layer. The schematic diagram of the structure is presented in Fig. 2. Two reference structures have been grown additionally. The first one (**B**) differs by the absence of CdSe FML (pure ZnSe QW), whereas the second (**C**) contains ordinary ZnCdSe QW of 25% cadmium content and emits in the same spectral range (500–520 nm). The general structure design has been reported elsewhere [6, 7]. The CdSe insertion provides an additional freedom in structure design, allowing one to vary lasing wavelength independently from the SPSL well and barriers composition.

The low-temperature PL and PL excitation measurements of the structure (**A**) (Fig. 3) confirm that the CdSe/ZnSe active region is very similar to the single 2.5 ML layer structure. The line is wider (80 meV) and slightly red shifted due to using of ordinary MBE growth mode at CdSe deposition [5]. The sharp ($\sim$ 7 meV) excitonic peaks from ZnSe QW are well-resolved in PL excitation spectra at the 500–516 nm registration wavelength. The peaks from ZnSSe/ZnSe SPSL are observed mainly at the registration wavelength corresponding to the emission from 10 nm wide ZnSe QW.

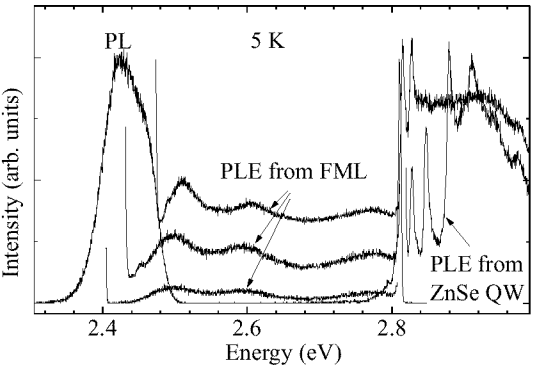

Fig 3. PL and PLE spectra of structure (**A**).

All structures demonstrate laser generation at room temperature. The wavelengths of laser generation of structures (**A**) and (**C**) are in the same spectral range but the threshold power density of structure (**A**) is almost 1.5 times lower than that of the structure (**C**) ((16–19) kW/cm^2 and (24–27) kW/cm^2, correspondingly). The structure (**B**) emits in blue region ($\sim$ 460 nm) with the $\sim$ 44 kW/cm^2 threshold power density that is practically lowest ever reported for II–VI's for this spectral range. In summary, the performed optical and structural characterization do not permit to conclude on the nature of the objects responsible for such high efficiency 300 K laser generation. The lasing arises in the spectral region where both dot-like and QW-like objects may emit light. Although more detailed studies are needed to elucidate the origin of this phenomena, the structures with CdSe FML active region are found to be extremely promising for green laser application, which respect to those with ordinary QW active region.

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